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The basic principles of narrow bandwidth telecommunications are treated in a manner understandable to the non-engineer. The comparative characteristics of the various narrow bandwidth communications circuits are examined. Currently available graphics transmission and reception equipment are described and their capabilities and limitations evaluated. A review of the most common difficulties encountered in the operation of graphics equipment is included with an assessment of the probable future development of graphics hardware and narrow-band transmission circuts. (Other papers from this conference are available as LI 003360 - 003375 and LI 003377 through LI 003390) (Author)

NARROW BANDWIDTH TELECOMMUNICATIONS

by

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ABSTRACT

The basic principles of narrow bandwidth telecommunications are treated in a manner understandable to the non-engineer. The comparative characteristics of the various narrow bandwidth communications circuits are examined. Currently available graphics transmission and reception equipment are described and their capabilities and limitations evaluated. A review of the most common difficulties encountered in the operation of graphics equipment is included with an assessment of the probable future development of graphics hardware and narrow-band transmission circuits.

INTRODUCTION

Narrow bandwidth telecommunications systems are perhaps more familiar to the layman than any other kind. Ordinary telephone and teletypewriter systems are common examples.

Before treating the subject matter in any detail, it might be well to specify precisely what is meant by the key words in the title. That is, what kind of systems are we talking about? What do we mean by Telecommunications? And, most important - how narrow is a narrow bandwidth? For that matter, what is bandwidth in the present context?

It is the objective of this paper to provide useful answers to the above basic questions and to discuss possible application of such systems to inter-library communications requirements and other information networks.

A system may be defined as an assemblage of elements or objects arranged in a coordinated manner to achieve a stated objective. In this instance, the objective is to transfer information translated into electronic form from one point to another. The information transmission and reception points are frequently referred to as the terminals of the system. These terminals are interconnected by means of a suitable transmission medium through terminal-to-medium interface units. The basic elements of such Telecommunications systems are illustrated in Figure 1.

The transmission medium is the electronic interconnection between the terminals and in the general case may consist of a pair of ordinary wires, coaxial cable, or a radio microwave system. The interface units provide the necessary compatibility between the requirements of the transmission medium and the characteristics of the terminal devices. The terminal devices are always some form of transducer which converts sound or light variations into desired forms of electrical variations or vice-versa. In the case of an ordinary telephone system, the terminal device would consist of the telephone handset.

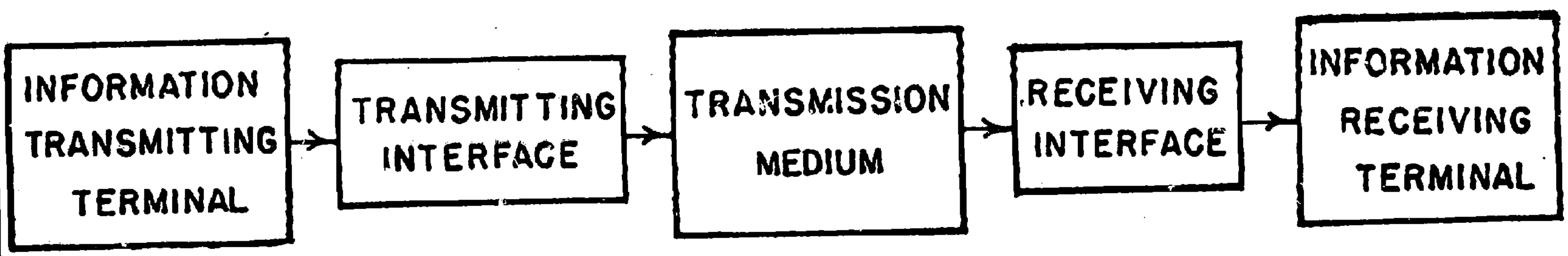

FIGURE 1: BASIC ELEMENTS OF AN ELECTRONIC TRANSMISSION SYSTEM

The term Telecommunications is a relatively new one in common use. Consequently, there is no universal agreement at this time on the precise meaning of the term. For the purposes of this paper, Telecommunications is defined as the electronic transmission of any information that can be translated into electrical signals.

Bandwidth is one of the most significant characteristics of an electronic transmission medium and may be defined as the frequency interval expressed in Hertz (cycles per second in the earlier terminology) which represents the frequency range between the lowest frequency and the highest frequency of electronics signals which can be successfully transported along a given transmission medium. The term narrow bandwidth is of course a relative one. The Western Union Company, which requires a bandwidth of only a few cycles per second (or Hertz) to provide teleprinter communications services, regard telephone circuits which employ a bandwidth of from 300 to 3000 Hertz as "broadband." On the other hand, the transmission of standard television signals requires a bandwidth extending up to four million Hertz. Clearly, the teletype circuit is regarded as narrow band in comparison with telephone requirements, and telephone circuits are regarded as narrow band in comparison with television requirements. Furthermore, television circuits may be regarded as narrow band in comparison with high-speed data links requiring bandwidths up to twenty or thirty megaHertz. For purposes of this paper, a narrow bandwidth is considered to be the bandwidth of any electronic transmission medium encompassing a frequency range of about 3000 Hertz or less. A transmission bandwidth of 2700 Hertz is conveniently economically available as a standard voice-grade telephone line, which extends from a lower frequency of 300 Hertz to an upper frequency of about 3000 Hertz.

Although narrow bandwidth telecommunications circuits are normally used for voice transmissions, it is one of the cardinal points of this paper that high resolution graphics can be exchanged between libraries over low-cost voice-grade circuits by exchanging transmission time for bandwidth, and hence cost, as shown in a subsequent section.

THE ECONOMICS OF TRANSMISSION CIRCUITS

One of the important non-technical characteristics of transmission circuits is that bandwidth costs money. That is, the greater the bandwidth requirement, the greater the cost. Furthermore, the cost is proportional not only to bandwidth but to the distance between the information terminals and the period of time over which the circuit is used.

The emphasis on narrow bandwidth telecommunications for inter-library use is based on the simple fact that narrow band circuits are far less expensive than broadband circuits and that such circuits are identical to ordinary telephone circuits and are thus universally available. Figure 2 is a graphical comparison of the approximate costs of leased full-period dedicated transmission circuits ranging from a teletypewriter circuit to a wide-band television circuit. One of the most striking conclusions that can be drawn through an examination of Figure 2 is that wide-band (four million Hertz) video transmission service is very expensive compared to narrow-band teletype and voice-grade service. nother striking conclusion is that dedicated teletype interconnections are not the bargains compared to voice-grade circuits one would logically expect when it is recognized that such circuits should require far less bandwidth than voice-grade circuits. This exception to the general cost-bandwidth rule is probably due to the fact that voice-grade lines are actually used for the teletype service. Furthermore, it is noted that due to the graduated mileage rate of the voice-grade circuit, the monthly cost for distance in excess of 360 statute miles is actually less than the teletype circuits. When the virtually universal applications of the voice-grade circuits for inter-library use are considered in comparision with the applications of the teletype circuits, the voice-grade circuits are clearly the most attractive.

The comparative economies of leased dedicated lines versus "dial-up" lines can be illustrated by examining a typical hypothetical system. The assumptions for the system are that high-resolution facsimile transmission is required between Jacksonville and Miami, Florida, and that the "standard" information to be transmitted is on an 8-1/2" by 11" document which requires a transmission time of four minutes. The station-to-station toll rate for a four-minute call between the two cities is $1.45. The per-month cost of a dedicated half-duplex (2-way)

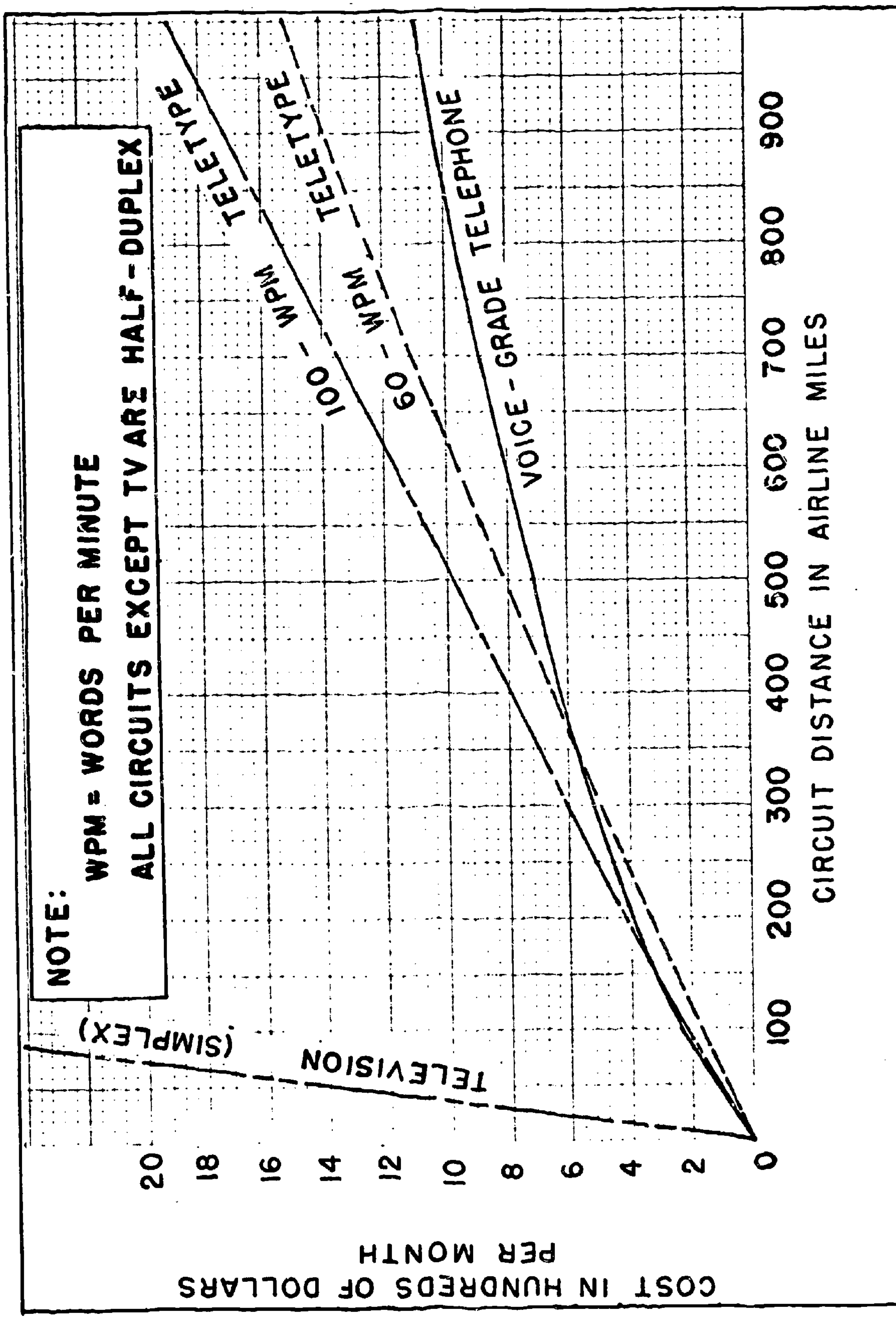

FIGURE 2: COMPARISON OF WIDE BAND & NARROW BAND TRANSMISSION COSTS

line between the two cities is $533.10. Figure 3 shows the cost per document relationship for the two systems under comparison. Examination of this figure reveals that to justify the cost of a leased dedicated line, the user must transmit at least 367 documents per month.

The reader should be cautioned against applying the information presented in Figures 2 and 3 to a specific requirement in a specific geographical area. The costs of transmission circuits provided by the common carriers are regulated by Federal (Interstate) and State (Intrastate) agencies, and in some states, by municipal agencies. The filed rate structures commonly referred to as tariffs are very complex. Therefore, it is usually necessary to contact the sales office of the common carriers in a specific area to establish the exact charges for the transmission services required.

BANDWIDTH, TIME, AND IMAGE-RESOLUTION TRADE-OFFS

One of the major cornerstones of modern electrical communications theory is the well-established trade-offs that are possible between bandwidth requirements, transmission time, and information, for a given transmission channel. Although the basic principles of information theory were suspected by early scientists such as Samuel F.B. Morse, the complete mathematical theory was not formulated until Claude Shannon enunciated the principles now known as the Hartley-Shannon Law.[1]

One of the major contributions of the Hartley-Shannon Law was a mathematically precise, objective definition of information.

A satisfactory definition and useful measure for "information" posed a problem to communication engineers not unlike the problem faced by the early classical physicists attempting to define work. Work, or the expenditure of energy is, and was, regarded as a subjective or physiological concept; i.e., people get tired

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1 "A Mathematical Theory of Communication," Bell System Technical Journal, Vol. 17, July and October, 1948.

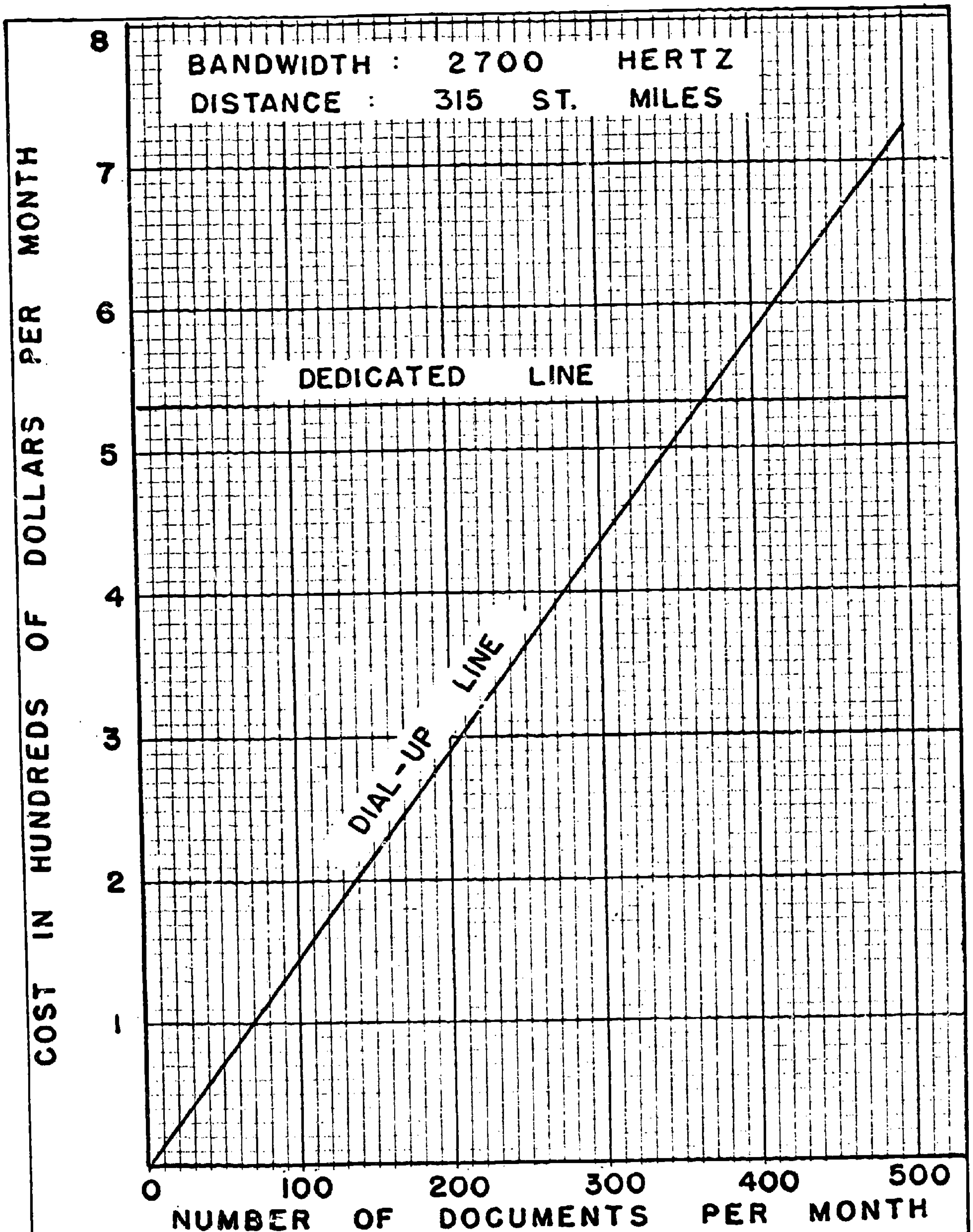

FIGURE 3: COMPARISON OF DEDICATED & DIAL-UP LINE COSTS

when they expend energy or do work. During the development of classical physics, it was found desirable to ascribe a non-physiological meaning to work which would lend itself to a purely physical definition, would be applicable to machines, and could be assigned useful units and measured. The result was the well-known physical definition:

$$\text{WORK} = \text{FORCE} \times \text{DISTANCE}$$

Or in symbols, $W = F \times D$

Thus, work, so defined, is measured in foot lbs. with F in lbs. and D in feet through which the mechanical force F acts, and as such, is purely physical and is therefore not a physiological concept.

The problems facing the formulators of modern communication theory were similar in that they were faced with the problem of defining information in precise mathematical terms so that it could be related to the known measurable parameters of a transmission system. A "message" contains no useful information unless it is <u>unpredictable</u> at the message destination point. Obviously, that which is predictable, calculable or known, is <u>not</u> news. In other words, news or information is something previously unknown, unexpected or unpredictable! This simple fact introduces the element of probability into the definition.

In striving for a precise definition and a useful unit of measurement, the communication engineer must eliminate the personal or subjective characteristics of information and stress its statistical properties. Therefore, he starts with the following relationship:

INFORMATION (I) = Logarithm to the base 2 of the probability (P).
In symbols:

$$I = \text{LOG}_2 P \qquad (1)$$

where the probability P is defined as equal to 1 if the event is certain to occur and equal to 0 if it is certain not to occur.

The remaining known important parameters of a communications system are:

T = Transmission time measured in seconds.
B = Frequency range or bandwidth in Hertz.
C = The communication carrier level in Watts.
N = The noise power level in Watts.

Through logical mathematical steps, Shannon combined the above parameters to form the following expression known as the Hartley-Shannon Law.

$$I = BT\ LOG_2\ (1 + C/N) \qquad (2)$$

For purposes of this presentation, the terms in bracket of equation (2) (1+ C/N) may be regarded as a constant K if the magnitude of the communicating carrier level C is maintained at some fixed level above the noise power level represented by N. Equation (2) may then be simplified to:

$$I = BT \log_2 K$$
$$\text{where } K = (1 + C/N) \qquad (3)$$

Equation (3) states simply that the maximum information that may be transmitted is directly proportional to the bandwidth, or frequency range, of the transmission system and the time available to make the transmission. The variable B (bandwidth in Hz) and T (time in seconds) have been previously defined. However, the definition of I (Information) requires some elaboration.

Using the most elementary signaling system (a well-know example: "One if by land, two if by sea"), we can arbitrarily establish two distinct signal levels, such as any finite level, or zero level; i.e., the presence of a given signal, or the absence of that signal. These two distinct levels or magnitudes are known as binary digits, either 1 or 0; YES or NO; a Mark or Space; "On" or "Off," etc. Coining a term by taking the first letter of Binary and the last three letters of digits, gives BITS, which is universally accepted as the fundamental measure of information, in equations (1), (2), and (3).

$$I = \text{BITS} = BT \log_2 K \tag{4}$$

Thus, information is measured in BITS and is simply - in a communication theory sense - the absence or presence of a binary signal. The implication of this definition - whether by design or accident - for machine-to-machine communication or communication between digital computers and man through appropriate coding procedures is evident. The interpretations and extensions of the Hartley-Shannon law are numerous. For our present purposes, the most important consequence is the conclusion that the communication engineer can exchange or "trade off" one parameter for another.

This fact becomes more evident through the use of a specialized form of the Hartley-Shannon Law applicable to the transmission of visual signals in which I, the information in BITS, is replaced by the RESOLUTION of the reproduced images. Such an equation becomes:

$$\text{Image Resolution} = K\left(\frac{B}{N}\right)T \tag{5}$$

Where K is a constant depending on the type of transmission system involved, N is the number of complete images transmitted, B is the frequency bandwidth in Hertz, and T is the transmission time in seconds. A dramatic example of the bandwidth-time trade-offs which are possible in an image transmission system can be given by considering the requirements for an ordinary television signal. Standard television, which is capable of providing the illusion of smooth motion in the reproduced image, utilizes a frequency range or bandwidth of approximately four million cycles per second (or Hz) to transmit <u>30 complete pictures</u> per second at an average resolution of approximately 400 lines over the entire picture. The relationship between resolution, the rate at which images are reproduced, and the bandwidth or required spectrum space required on the transmission channel can be summarized by a minor variation of equation (5) above, as follows:

$$\text{Image Resolution} = K\left(\frac{B}{M}\right) \tag{6}$$

Where K and B are as defined above and M is now the number of complete pictures transmitted per second.

It can be readily seen that bandwidth B can be scaled down by the same factor that the number of complete pictures per second M is scaled down, without affecting the magnitude and ratio and hence image resolution. Applying this principle of "trade-offs" to electronic transmission systems reveals that if the picture transmission rate is reduced from 30 per second to one per minute (a factor of 1800), the bandwidth requirement can be reduced from four million Hertz to a mere 2200 Hertz! This bandwidth requirement is well within the range of an ordinary 2700 Hertz voice-grade telephone line.

Thus a series of sixty still pictures such as slides, film strips, charts, pages of a book or periodical, etc. could be transmitted over an ordinary narrow bandwidth voice-grade telephone line at a rate of one document per minute with a resolution comparable to that of television. If higher resolution is required, the transmission time could be increased to two hours for the sixty documents to achieve a line resolution in the reproduced image twice that of conventional television.

COMMONLY AVAILABLE TYPES OF TRANSMISSION CIRCUITS

Transmission circuits to interconnect the terminal equipment discussed in the previous section are available to the telecommunications user in the following ways.

1. Privately owned.
2. Leased.

A comparison of the cost of privately owned circuits vs. leased circuits is too complex to discuss in this presentation. The final choice is usually based on the types of funds available, i.e., capital or operating, and the period of time over which the transmission circuits are required.

Leased transmission circuits may be further categorized as "Dial-up" (Direct Distance Dial), or Leased (dedicated). The transmission bandwidths are generally similar for both circuits but other characteristics may differ appreciably depending upon whether analog or digital signals are to be carried. In the simplest terms, analog signals are continuously variable electrical signals which are directly proportional to some characteristics of the information to be transmitted. Voice signals are good examples of analog signals. Digital signals, on the other hand, generally exhibit only two magnitudes - zero and the maximum permissible value. The information to be converted to digital signals must almost always be encoded in some manner. Ordinary Morse code and teletypewriter signals are familiar examples of encoded digital signals.

Transmission circuits may also be categorized as simplex, half-duplex, and full duplex. These classifications refer to the simultaneous or non-simultaneous directions of operation as illustrated in Figure 4. It is worhwhile to note that the transmission characteristics of the opposite-direction channels of an inter-city duplex circuit may be completely independent. Accordingly, it is practical to tailor the transmission bandwidth to the actual requirements in each direction. Obviously, if the transmitting and receiving terminal equipments are identical (such as they are in a full-duplex telephone circuit), the requirements of the transmission circuits would be identical.

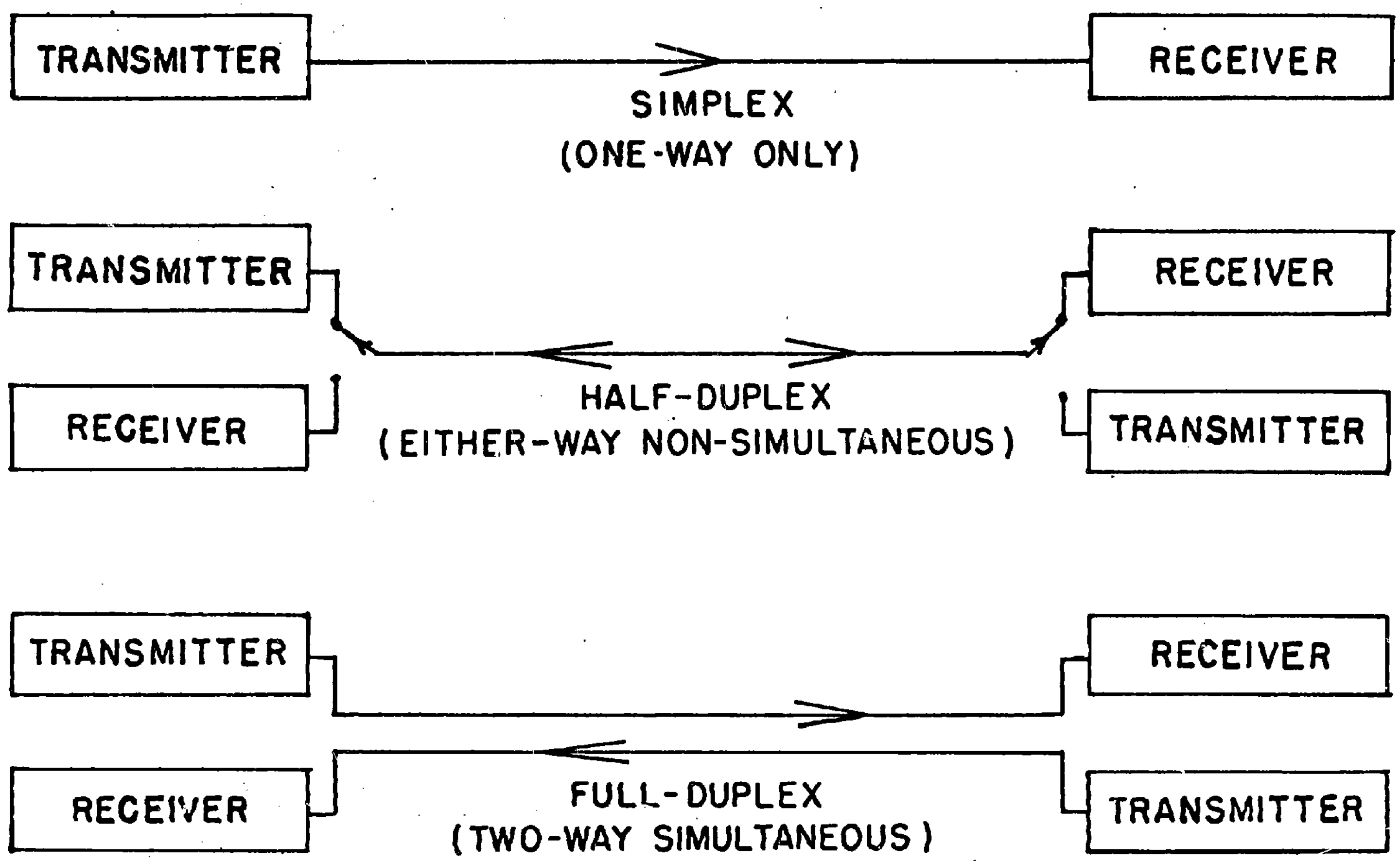

FIGURE 4: TYPES OF COMMON TRANSMISSION CIRCUITS

TERMINAL EQUIPMENT COMMONLY AVAILABLE FOR GRAPHICS TRANSMISSION AND RECEPTION

There are many options open to the user who wishes to transmit graphic information from one point to another electronically. The following paragraphs constitute a brief discussion of the more important devices.

The Teleprinter

One of the oldest and still the most common devices in use is the teleprinter, most commonly called a teletype machine. Although "teletype" refers to the equipment manufactured by the Teletype Corporation, they are by no means the only teleprinter manufacturer.

Teleprinters are useful primarily for message transmission since it is necessary to "type" the information to be transmitted on the teleprinter keyboard at the sending end. Once typed, the information can be stored for future retransmission. The most common storage medium is punched paper tape, although magnetic tape may also be used.

One form of message which does not have to be "typed" on the teleprinter keyboard is the output of a computer, and teleprinters are widely used as remote computer output terminals.

Teleprinters, of course, produce hard copy and many teleprinters are equipped with an integral paper tape punch and reader. The punch permits preparation of copy in advance of transmission and even allows error correction, in that the tape can be corrected by striking over errors and retyping a misspelled word or ungrammatical sentence. The punched tape can be saved for future retransmission of a message. The paper tape punch can also be used on the receiving end of a teleprinter system. This permits the "recording" of an incoming message so that multiple copies may be prepared.

When teleprinters are used with dial-up circuits, "real-time" operation of the machines is somewhat wasteful, since the operator cannot type at the 60 or 100 WPM transmission rate capability of the circuits. Savings in line costs can result if the message is typed in advance of transmission at normal typing speed, and "recorded" on punched paper tape. When the message is completed and checked for correctness, connection with the receiving teleprinter can then be established and the message "played back" on the tape reader at the full 60 or 100 WPM capability of the circuit.

Most teleprinters are used in conjunction with the world-wide TWX or TELEX public networks. Any subscriber on these networks can reach any other subscriber on a dial-up basis, and either "converse" with the other party or send a "one way" message to an unattended machine. Many private teleprinter networks are also used by industry, such as airlines, and by law-enforcement agencies and the military. Recently developed teleprinters even allow reception of teleprinter messages by mobile radio telephone systems in vehicles.

Teleprinters need not be two-way devices. A print-only device without a keyboard may be installed at those locations where only message reception is desired.

Teleprinters may be characterized as "medium speed" devices. Those in message service operate at a maximum speed of from 60 to 100 words per minute, somewhat beyond the capabilities of an average typist.

In general, teleprinters are limited to the transmission of printed text materials. Elementary graphs and charts can be produced, however, by "drawing" lines made up of periods, X's, or other characters. Some ambitious teleprinter operators have even produced crude pictures using various letters and numbers to approximate half-tones. However, these pictures are very time-consuming to produce and are really only novelties.

The teleprinter uses a digital code for each letter, number, and symbol on the keyboard, and transmits the code as a series of on-off pulses, or in some systems, as a series of tones. If one were to connect a speaker across a teleprinter line, the signals would sound very much like Morse Code.

The on-off pulses are arranged in 7-unit, or "7 bit" digital code. The letter A, for example, is sent as a 7-bit sequence: off-on-on-off-off-off-on. The word "CAT" is the rather tedious sequence:

Off-off-on-on-on-off-on
Off-on-on-off-off-off-on
Off-off-off-off-off-on-on

While this on-off code is certainly an awkward method of communication in human terms, it is ideal for machines and digital computers in particular. The teleprinter code can be transmitted over very narrow bandwidth channels. For example, up to 15 separate 100-wpm teleprinter channels can be accommodated in the 300-3000 Hertz bandwidth, which is required for a single telephone conversation. The teleprinter code is also highly immune to noise or "static" and has a very low transmission error rate even on a noisy transmission circuit.

The on-off transmission code is, of course, ideal for communication with computers since the on-off digital code is the basic internal language of all digital computers.

There are three basic types of teleprinter mechanisms. The most common type is the impact printer in which a typing bar or element strikes a typewriter ribbon in contact with paper, just as in a conventional typewriter.

An electrostatic printer places a wire matrix in contact with paper which darkens when an electric current is applied.

A recent and unique printer is the "Inktronic" printer introduced by the Teletype Corporation. The characters on this printer are formed by a thin stream of fast-drying ink, which is "squirted" onto the paper while being electrostatically deflected to form the desired character.

Within the past three years there has been a proliferation of new teleprinters, due to tne demands of the computer industry for these devices. The newer teleprinters are more compact than previous devices, and in general more economical.

Many companies are producing adaptors which convert standard office typewriters into teleprinters. The most popular adaptation makes use of the IBM "Selectric" typewriter which is capable of higher speed operation than conventional machines.

Telefacsimile

The most significant differences between telefacsimile and teleprinter systems, is that the user need not type out the material on a keyboard - the entire document can be transmitted merely by placing it in the machine. Another important difference is that the facsimile machine can transmit line drawings and continuous-tone material such as photographs, as well as printed text. In fact, one of the common uses of facsimile is the transmission of newspaper photographs. When used for this purpose, facsimile is referred to as "Wire-photo" or "Radio-Photo" transmission.

The document intended for transmission on a facsimile system must be placed on a rotating drum, or on some of the more elaborate machines, on a flat bed. This requirement imposes some serious limitations for library use of facsimile since bound documents generally cannot be placed in the machine. The usual expedient is to make an intermediate copy of the desired material on a copier, such as a Xerox machine, and to feed the intermediate copy into the facsimile machine for transmission. This procedure is not only expensive and time-consuming but even worse, results in very poor resolution and grey-scale rendition in the reproduced copies at the receiving terminal due to the degradation introduced by the intermediate copy. This limitation on facsimile transmission can be readily solved by redesign of the facsimile transmitter. However, demand for transmission of bound materials has apparently not been sufficiently great to persuade manufacturers to produce suitable machines.

Once the copy has been placed on the drum of the facsimile transmitter, the drum begins rotating and the copy is scanned by a photocell moving along the length of the drum. The copy is scanned from left to right in a helical pattern resembling the threads on a bolt. The photocell responds to changes in the lightness and darkness of the copy on the drum, and converts these changes into proportional changes in electrical voltage. The voltage, in turn, is made to vary the pitch of a tone which is transmitted as the facsimile signal. If one were to listen to a facsimile line, a signal would be heard which sounds like a rapidly varying whistle.

Recall that the signal from a teleprinter sounds like Morse Code - a series of on-off tone pulses which constitutes a digital signal. The facsimile signal on the other hand is an analog signal and for this reason is more difficult to transmit than teleprinter signals. Analog signals may be considered more "fragile" than the simple "on-off" digital teleprinter signals. Therefore, the transmission of facsimile signals over a low-quality transmission system may cause severe distortion of the received copy. The bandwidth required for facsimile transmission is greater than that required for teleprinter transmission and like teleprinter transmission, the bandwidth required is a function of the speed of transmission.

At the receiving end of a facsimile system there is another rotating drum, revolving at exactly the same speed as the drum on the facsimile transmitter. To accomplish this, a synchronizing signal accompanies the facsimile information to insure that the two drums remain locked to one another. A scanning head on the facsimile receiver follows exactly the same spiral path as the photocell in the transmitter. In most facsimile receivers, the scanning head contains a small wire stylus which contacts a special paper attached to the drum. This treated paper darkens when current is applied from the sytlus, and the degree of darkness is a function of the strength of the applied current. Since the current applied to the stylus is proportional to the lightness or darkness of the copy as seen by the photocell on the transmitter, the stylus produces a faithful copy of the original material.

There are variations on the facsimile process just described. Some facsimile machines intended for high-quality photographic reproduction use light sensitive photographic paper at the facsimile receiver. Although the quality is significantly better with this process, the photographic paper must be chemically processed in a photographic darkroom. Some facsimile receivers, generally the more expensive ones, use an alternate scanning system, abandoning the drum for a linear scan system which produces copy on a long roll of sensitized paper. These machines require less effort on the part of the operator at the receiving system, since he is not required to place a new sheet of paper on a drum for each new document received. These roll-fed receivers are thus suitable for unattended operation.

Numerous variations of and accessories for the facsimile machine are available. Machines are available for the transmission of microfilm and microfiche cards, some machines permit enlargement or reduction of copy size and there are machines capable of transmission of full color facsimile.

Slow-Scan Television

The electromechanical facsimile process has an all-electronic counterpart in slow-scan television. However, slow-scan television is similar to facsimile only in its basic principles of operation, which involve the scanning process.

Although true slow-scan television is not commonly used, it is the most readily understood system and therefore merits discussion here since it is the basis for the more sophisticated "sampling" system.

In conventional television, a rapidly moving beam traverses the screen, and because of the physiological characteristic of persistence of vision, the moving beam or "dot" is perceived as a line. The beam traces 525 lines to form a complete television picture, and forms one picture or "field", every 1/30th of a second. As the dot traverses or "scans" the TV receiver screen, it varies in brightness in proportion to the darkness or lightness of the picture being reproduced.

In conventional television, information is transmitted at an exceptionally rapid rate - 30 separate pictures per second, 15,750 individual lines per second. The price for such rapid transmission rates is bandwidth, and the conventional television system uses a bandwidth of four million Hertz, - enough to accommodate 1000 simultaneous telephone conversations or 20,000 separate teleprinter channels!! Because of the cost/bandwidth relationship in transmission systems previously discussed, conventional television transmission systems are very expensive.

Economical transmission of television type signals can be achieved by slowing down the scanning process to achieve a practical trade-off between bandwidth and time. For example, in conventional television, the beam moves across the screen in 63.5 millionths of a second (63.5 microseconds). If the scanning speed is reduced by a factor of 1800 as in the earlier example, one scanning line will occupy a period of 63.5 x 1800 microseconds. Therefore, a complete 525 line picture will occupy a period of 60 seconds. The bandwidth requirements are also reduced by a factor of 1800, so that the signal is accommodated in 2200 Hertz which is the bandwidth of an ordinary voice-grade channel.

The "soft copy" display at the receiving terminal is displayed on a special slow-scan monitor. The display tube in the slow-scan monitor is equipped with a <u>high persistence</u> screen which continues to glow a short time <u>after</u> the beam has passed. This high persistence screen replace persistence of vision which is effective only with the high speed visual stimuli of conventional television.

Unfortunately, reproduced pictures on true slow-scan TV are generally unsatisfactory compared to conventional television. The screen will be uneven in bright from top to bottom due to the decay characteristics of the high persistence tube and the color of the image will be either green or blue, since white phosphors with high persistence are not available. Any motion in the original picture will result in a blurred image because of the long "exposure time". The cause and effect of the blurred image are the same as that which occurs in conventional photography when one attempts to photograph a moving scene using a slow shutter speed.

Because of these limitations, true slow-scan TV is seldom used. Instead, a scan conversion process is employed which permits the use of standard TV cameras at the transmitting terminal and conventional TV sets or monitors at the receiving terminal. In such systems the interface components shown in Figure 1 would include the necessary scan converters. In such systems, the reproduced display at the receiving terminal looks almost identical to a stationary television image. Each time new material is transmitted, the new picture "wipes" across the screen from left to right, displacing the old picture in the process.

The terminal hardware for transmission of graphics via slow-scan TV can be exceptionally simple. An inexpensive vidicon TV camera, some lighting equipment and a slow-scan converter at the transmitting end and a receiving slow-scan converter and an ordinary TV monitor at the receiving end. Recording the slow-scan signal for future viewing or retransmission can be accomplished with an ordinary audio tape recorder. If a stereo recorder is used, one channel can be used for the picture information and the second channel for an accompanying audio commentary.

Slow-scan television can be used to accomplish the same functions as a facsimile machine where a hard copy is not required. Transmission of copy from books is somewhat easier than with facsimile since the camera can be focused on a page, or portion of a page, without the need to mount the book page on the rotating drum or copy bed, as is required with facsimile.

Slow-scan TV is ideal for the transmission of a sequence of still pictures, such as film-strips, 35 millimeter slides, overhead transparencies and the like. Group viewing is possible and the number of viewers limited only by the number of available television receivers. Large group viewing is possible with a single large screen television projector for use in auditoriums.

The picture can be accompanied by a sound-track transmitted, or recorded and played back, on a separate audio circuit.

Stylus Writer

Stylus writers may be called remote "electronic slates". At the stylus-writer transmitter, the sender writes or sketches on a special surface and at the receiver, a pen duplicates the writing by following exactly the movements of the sender's pen or stylus to produce a hard copy. Like the teleprinter, the stylus writer is a message-type device, that is, it is not suitable for the reproduction of existing documents such as those transmitted by facsimile or slow-scan TV. Unlike the teleprinters which require typing skill, the stylus writer requires only that the sender be able to write legibly. Normally, the stylus writer "receiver" is used by only one person at a time, however, an accessory device does make group viewing possible. This accessory device is a special overhead projector which projects the "screen" of the receiving stylus writer on to a standard projection screen as shown in Figure 5.

The stylus writer is also a narrow-bandwidth device which operates satisfactorily over ordinary voice-grade circuits. Its operational principles are quite simple. The transmitter senses the movement of the stylus in the X and Y axes - that is, it senses both the up and down and left and right movement of the stylus. Two separate signals are transmitted as varying tones, one signal for the X-axis and one for the Y-axis. At the receiving end of the system the control tones operate separate X-axis and Y-axis motors which cause the receiver's pen to follow the position of the stylus at the transmitter.

The signals of the stylus writer can also be recorded for delayed transmission on an ordinary audio tape recorder.

The stylus-writer, because of its simplicity of use, has become popular as a form of "written-intercom" system.

Blackboard-by-Wire

A close relative to the stylus writer is the Blackboard-by-Wire system which "marries" the stylus writer with television. Basically, the Blackboard-by-Wire system replaces the stylus writer hard copy receiver with a conventional television receiver which provides a soft copy display. This permits large-group viewing of the stylus-writer messages and ready distribution of the material over existing television distribution systems.

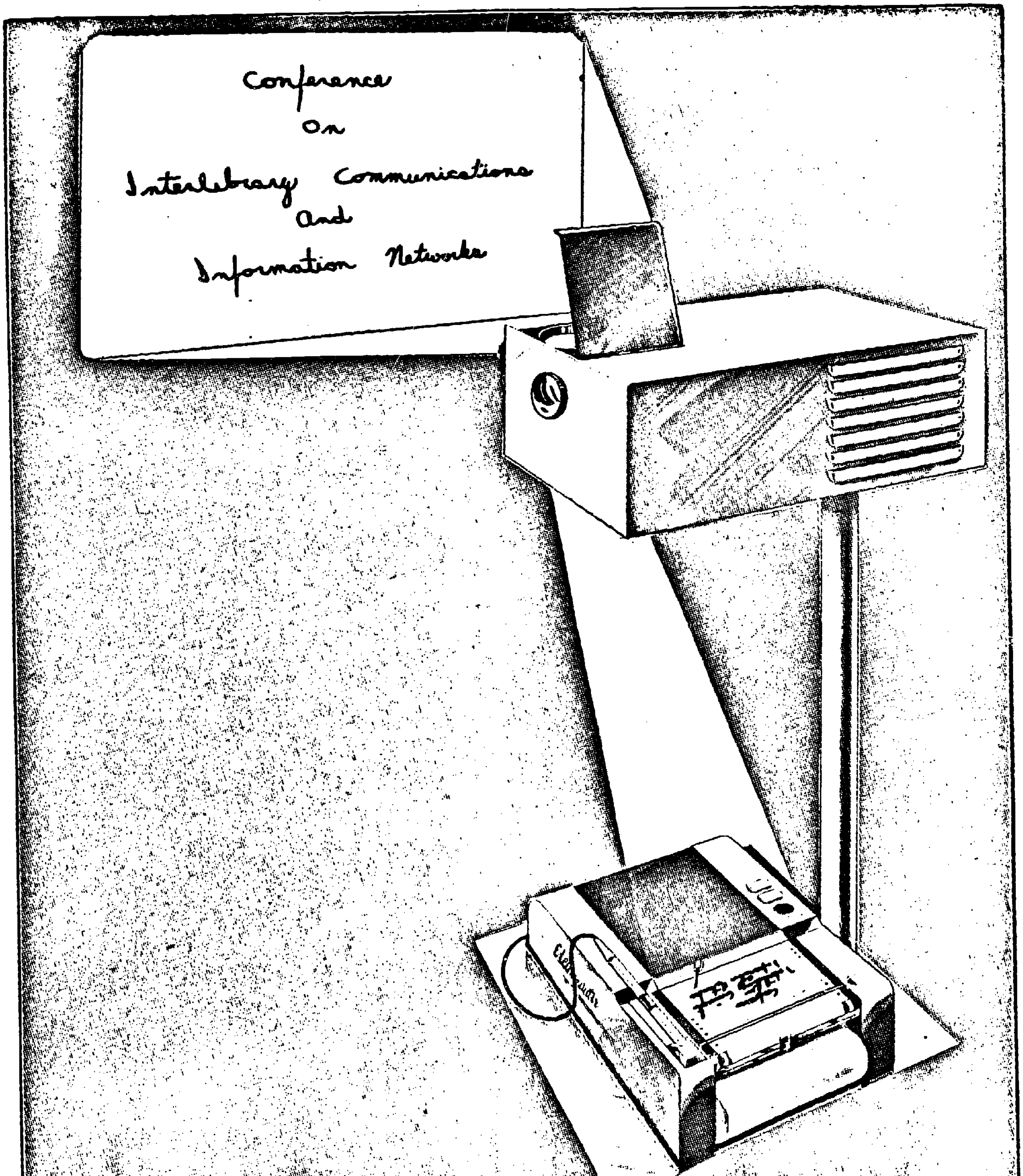

FIGURE 5: ELECTROWRITER PROJECTION SYSTEM

The Blackboard-by-Wire system is almost identical to the stylus writer at the sending end. At the receiving end, however, the X-axis and Y-axis signals go to an electro-optical converter which produces a standard television signal at its output. On the television receiver screen, the written or sketched material can appear as black writing on a white background or white writing on a black background. The moving dot which produces the image on the TV screen follows, or is "slaved" to the point of the stylus at the transmitting end.

Like every good blackboard, the Blackboard-by-Wire comes equipped with an eraser, simply a pushbutton at the transmitting end which blanks out the TV screen to provide a fresh writing surface.

Like the stylus-writer, the Blackboard-by-Wire is useful for message transmission - the video intercom idea. It is also a valuable instructional tool and when used for instruction purposes it is almost always accompanied by an audio channel. Group viewing is easily accomplished by using multiple television monitors or receivers or a large screen television projector. The Blackboard-by-Wire signals can also be recorded on an audio tape recorder and if a stereo recorder is used, the accompanying audio track can be recorded on the second channel.

Machine Readable Data

To this point narrow-band devices which involve person-to-person communication have been treated. Today there is also a requirement for person-to-machine communication and vice-versa.

The teleprinter discussed earlier is a common terminal for use with a computer, and many conversational computer languages such as BASIC, FOCAL, and APL permit "interactive dialogue" between the user and the machine. The teleprinter provides a hard copy of both ends of such a conversation. When a hard-copy of the conversation is not required, a device called a Cathode Ray Tube Terminal, or simply "CRT Terminal" is used. This device is similar to a teleprinter, except that the printed text appears on a television-type screen instead of being typed on a sheet of paper. This is the only basic difference in the two devices. The keyboards of the teleprinter and CRT Terminal are identical and the CRT terminal is "plug-compatible" with the teleprinter - that is, the terminal may be directly substituted electronically for the teleprinter.

When it is necessary to receive graphs, sketches and other such nonprint data from the computer, it is necessary to use a sophisticated version of the stylus writer called a plotter. The principles of operation of the plotter are identical to the stylus writer, except that greater accuracy is required, and the signals are generated by the computer rather than by a user tracing a sketch or writing with a stylus. In addition, the data is presented to the plotter in digital, rather than analog form.

The computer readily accepts data from a teleprinter or CRT Terminal since the output of these devices are digital code signals in the internal code language of the computer. Another medium suitable for feeding data into the computer is the ubiquitous computer card. The most common version is the punched card which is produced on a card punch with a keyboard similar to that on a teleprinter. A unique hole pattern is punched into the card columns for each letter, number and symbol on the keyboard. The letter, number or symbol is simultaneously printed at the top of the card.

The information on the card is transmitted to the computer by a card reader which reads the hole patterns in the card, converting them into tone-coded signals suitable for transmission on a voice-grade telephone line. As with the other media we have examined, the required bandwidth is a function of the speed of transmission. Over a voice-grade line, the maximum number of 80 column cards which can be transmitted is approximately 12 per minute. Cards need not be punched to be transmitted. The so-called "mark-sense" card can also be used. The mark-sense card is coded by filling in boxes on the card with a pencil. Generally the mark-sense card is laid out in a "multiple-choice" format. For example, if the card is used to indicate a selection of books by title and quantity, each of the titles would be printed on the card followed by a box after the title. The user would darken the boxes following the desired title, with a lead pencil. Once completed, the card is fed into the reader, which recognizes the marked boxes and transmits the information to the computer in the form of a digital code.

Devices are also available which permit direct transmission of typed or hand-printed documents to the computer. These devices, called OCR Equipment, for Optical Character Recognition, scan typed or hand-printed copy, identify the discrete letters or numbers and derive from them a unique digital code for each character. Obviously, the OCR equipment greatly improves the man/machine interface, however, as usual, there is a price. In this instance the price paid is a high error rate, compared to other devices, and high cost of the OCR equipment. Due to these limitations, use of OCR equipment is not yet widespread.

Magnetic Tape

Magnetic tape has been the classic storage medium for computers and almost every computer center has at least one row of high-speed and high-cost tape drives. For narrow-band telecommunications these high speed devices are not necessary and information may be stored on small inexpensive slow-speed recorders which utilize 1/4 or 1/8 inch tape of the quality generally used for audio recording. Several manufacturers provide recorders using cassettes - which are convenient to use and store. The available magnetic tape drives are also suitable for digital data recording and are thus compatible with teleprinters, punched paper tape, punched and mark-sense cards, and OCR equipment. The drives can be used to accumulate data which is stored and then forwarded to a computer. They are also valuable for storing files of frequently used data and "canned" computer programs.

Magnetic tape is also suitable for the storage of analog signals such as those from facsimile machines, stylus writers, and Blackboard-by-Wire equipment. As mentioned previously, these signals may be recorded on a high-quality audio recorder. The recorders used for this application should have precise speed control since speed variations which would be almost unnoticeable in the reproduction of sound can cause serious distortion in the reproduction of facsimile and other "picture" devices. Some devices are more sensitive to speed irregularities than others and for some of these devices high quality reproduction requires recorders with servomechanism speed control.

THE INTERCONNECTION OF NARROW BAND TERMINAL DEVICES

Prior to June, 1968, connection of graphics equipment to a dial-up line had to be accomplished through the use of special equipment owned and installed by the telephone company since the telephone subscriber was prohibited by the telephone tariff regulations from attaching "foreign equipment" to the telephone lines. Thus graphics and data handling equipments were connected to the dial-up lines through a special device provided by the telephone company known as a DATA PHONE or DATA SET. Such devices were ordinary telephone instruments with an interface built into the base of the telephone for use with a particular terminal device.
Furthermore, the telephone company provided a separate Dataphone or Data Set for each type of terminal device! As if to add insult to injury, use of the Dataphone incorporating a particular interface was necessary even though the terminal equipment owned by the subscriber included the same interface device! Obviously, the use of different types of graphics and data transmission terminal equipments by a particular subscriber such as a large library presented a ludicrous situation.

On June 28, 1968, the Federal Communications Commission ruled that the telephone tariff regulations were unreasonable and unduly discriminatory. In deciding the Carterphone Case which was primarily concerned with the connection of mobile radiotelephone equipment to the dial-up network, the Commission said:

> "We hold that the tariff is unreasonable in that it prohibits the use of interconnecting devices which do not adversely affect the telephone system."[1]

As a result of the Carterphone decision, telephone subscribers using graphics equipment now have the option of using a telephone company supplied data set, or supplying their own interface equipment and interconnecting with the

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1 In the Matter of Use of the Carterphone Device in Message Toll Telephone Service. 13 FCC 2d. 423

telephone system in one of two ways:

1. Appropriate interface equipment can be physically connected or "hard wired" to the telephone lines via a Data Access Arrangement (DAA) supplied by the telephone company. The DAA is a common telephone instrument equipped with a simple switch to connect or disconnect the graphics equipment from the telephone line. When establishing a connection with the DAA, the subscriber uses the DAA as a conventional telephone, and can converse on the telephone handset. When it is desired to activate the graphics devices, the subscriber depresses a pushbutton on the DAA which disconnects the handset and connects the graphics equipment to the line. A $2.00 per month surcharge is made by the telephone company for providing the DAA feature. This surcharge is in addition to the usual service charge for the telephone instrument and line.

2. The terminal equipment and appropriate interface can be "attached" to any common telephone instrument via an <u>acoustic coupler</u>. No direct "hard-wired" connection is made to the telephone lines, and no special telephone company supplied equipment is required. With an acoustic coupler, the telephone handset is placed in a holder on the acoustic coupling device so that the telephone handset receiver and transmitter are in contact with a small speaker and microphone in the acoustic coupler. The tone-coded information from the interface is fed to the speaker and coupled into the telephone handset transmitter. The received tone-coded information appearing at the telephone handset receiver is coupled into the microphone in the acoustic coupler unit, and the amplified signal fed into the receiver interface for "de-coding". The acoustic coupler is widely used with portable graphics terminals since it permits connection of the terminal to <u>any</u> telephone instrument by simply placing the handset into the coupler.

SIGNIFICANT PROBLEMS

Problems in the utilization graphics of transmission systems fall into two general categories - technical problems and people problems. Technical problems can be further subdivided into equipment malfunctions, transmission impairments, and problems associated with exceeding the capabilities of the hardware.

Equipment malfunctions are inevitable in the best of hardware "families". They can be reduced by the application of scheduled routine maintenance procedures. Equipment down time, once a malfunction has occurred, will depend on whether the equipment is maintained by your own staff or by an outside agency.

If the equipment is to be maintained by the company which installs it, the quality of their service and their "call-out" time should be a factor in deciding which company to deal with. In many instances this factor is as, or more, important than the type of equipment supplied, or its cost.

Transmission impairments are a frequent problem in graphics transmission. Seldom does the telephone line go completely dead - however, its frequency response, distortion, and noise characteristics can change without warning.

The effect of these abnormalities will depend on the type of equipment being used and on the importance an error or distortion will have to the user. For example, a transmission impairment which results in a misspelled word in the text of a teleprinter message may be inconsequential when the teleprinter is being used in message service, since the correct spelling of the word may be evident to the party receiving the message. When the teleprinter is used to communicate with a computer, however, the correct spelling - or worse, the transmission of an incorrect number, will not always be evident to a machine and erroneous output will result.

The dedicated telephone line will generally provide better and more reliable service than dial-up lines; however, when a bad dial-up line appears, the user can usually obtain a satisfactory line by replacing the call.

The degree of transmission impairment difficulty encountered will also depend on the geographical area in which your facilities are located. Certain areas of the country have notoriously poor telephone service. In such instances, the dial-up lines are often not even satisfactory for normal voice communication, let alone adequate graphics transmission. In these areas, a dedicated line is almost mandatory even for intracity graphics transmission.

The performance and reliability of the telephone service is a factor outside of the direct control of the user. A certain indirect control can be exercised, however, by frequent and vocal comment to appropriate telephone company officials when things do go awry, and if necessary, the filing of formal complaints with the appropriate regulatory agencies.

Occasionally, poor performance in a system is a result of attempting to transmit information which is beyond the capabilities of the equipment. This problem arises when one tries to transmit extremely small print on a facsimile system, for example. The average facsimile system has a maximum resolution capability of approximately 80 lines per inch, which, as a practical matter, means that printed letters less than 1/16 of an inch high will be "fuzzy" and indistinct. A similar difficulty arises when one tries to transmit pictures with subtle gray scale values over slow-scan television since slow-scan television is limited to the reproduction of a maximum of 10 shades of gray at best.

These problems can be best prevented by carefully defining the required performance of the graphics system <u>before</u> the equipment is chosen and installed.

It is to be expected, however, that there will be occasional instances wherein equipment is taxed beyond its limitations. This just seems to be part of human nature. In these instances, it is only possible to advise the user that the reproduction quality will be less than ideal, and hope for the best.

The "people problems" affecting narrow-band graphics transmission equipment are most difficult to analyze and treat. In general, both the disseminators and users of graphic information have set patterns in their information-seeking habits that are not easily changed. The proponent of graphics transmission systems must have an almost evangelical zeal to stir even mild interest in the use of his system. He must contend with such criticisms as "Why did we purchase that when my department needs a new*." When an equipment failure occurs, there can be almost a Greek chorus of "I told you so's." And an employee who is asked to operate a teleprinter in addition to his regular duties, is liable to react as if you just asked him to scrub the entire exterior of the building with a toothbrush.

The impact of these various people problems can be minimized by careful systems planning, and the introduction of new hardware on a gradual, scheduled basis. A small-scale pilot program is often valuable as a means for testing assumptions regarding need and utilization patterns without the investment required for a full-scale system. The pilot program also permits the staff to become familiar with the new services on a gradual basis.

FUTURE POSSIBILITIES

One of the most critical needs in the general field of narrow bandwidth graphics transmission systems is the introduction of low-cost reliable terminal equipment. Briefly, during the past few decades, we have witnessed numerous technological breakthroughs. The decade of the '70's is now ready for a significant economic breakthrough. Such economic breakthroughs will occur only when engineers apply their talents to cost reduction and volume production, and enlightened consumers actively promote large-scale acceptance and utilization of such equipment. Virtually all of the terminal equipment discussed in this paper is less complex, technically, than the ordinary television receiver, but has a price tag 10 to 20 times the cost of a TV receiver. Volume production and competition between manufacturers will serve to equalize this price difference. The introduction

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*Adding machine, broom, candlestick, doorknob, eraser, and most important--higher staff salaries!

of LSI (Large Scale Integration), microcircuits will serve to further reduce costs, but this circuitry too, is only feasible when high volume production is involved.

Some future cost reductions may be expected in the transmission media for narrow bandwidth equipment. It is technically possible now to utilize the SCA (Subsidiary Communications Authorization) subcarriers on FM broadcast stations for the transmission of narrow bandwidth graphics signals. Utilization of the SCA will permit simplex transmission to an unlimited number of receivers in the coverage area of an FM station.

In the past years the FCC has broken the telephone company monopoly on common carrier data transmission systems, and has granted licenses to several special-service common carriers to establish "public" data communications systems. With this competition there is a possibility that we will also see reduced rates for dedicated leased lines and other related services in the near future. It is also possible that transmission quality on the data-transmission lines will be somewhat better than that provided by the telephone company - since the data-transmission lines will be optimized for data rather than voice.

SUMMARY AND CONCLUDING COMMENTS

Frequently, when the application of new technology is considered in any area of interest, there is an inclination to consider a given new device as an end in and of itself. The new device is installed - the staff made aware of its fantastic capabilities and commanded to use it. After a few months of experience, it is "concluded" that the new device provided a solution for a problem which never really existed. Therefore, the device is generally relegated to the nearest dark closet. The moral, of course, is that technology itself has no inherent properties of magic. For reasonable expectations of success in the introduction of technology into an existing system, there appear to be at least three prerequisites:

1. The technology must meet a realistic need which has been clearly defined.

2. It must be integrated into the system gradually to permit user training and acceptance.

3. It must be supported. Funds must be made available for operating personnel, service personnel and supplies and maintenance.

It is inappropriate for the telecommunications engineer - regardless of his qualifications - to attempt to define the needs of libraries for Graphics Hardware. These needs are best defined by the innovative librarian. The most valuable service the engineer can render is to provide accurate information on the capabilities and limitations of existing hardware which, incidentally, has been one of the objectives of this paper. The capabilities of the hardware discussed to this point can be summarized as follows:

1. Teleprinters - Hard copy message-handling device. Economical of bandwidth - excellent man/machine interface with computers. Limited to transmission of the printed word. Storage possible on paper or magnetic tape.

2. CRT Terminal - Soft copy version of the Teleprinter.

3. Facsimile - Hard copy device which reproduces the original document. Suitable for transmission of printed word, line copy, or continuous-tone copy. Storage possible on magnetic tape.

4. Slow-scan Television - "Soft copy" device which reproduces original document or scene viewed by the television camera. Large group viewing possible. Readily accompanied by audio commentary. Storage possible on magnetic tape.

5. Stylus Writer - Hard copy message-handling device which transmits handwriting or drawing to a remote location in real time. Storage possible on magnetic tape.

6. Blackboard-by-Wire - Soft copy version of the stylus writer with display on TV screen. Group viewing possible. Storage possible on magnetic tape.

7. Machine Input Equipment:

   a. Punched and Mark-Sense Cards
   b. Magnetic Tape Drives
   c. Optical Character Recognition Devices

The only intrinsic limitation of any of the above narrow-band devices is the limitation on transmission speed and hence an inability to reproduce motion. Their application to inter-library graphics transmission is limited only by the creativity of the user. The most obvious advantage of narrow-band graphics technology is its ability to extend the resources of a library beyond the actual physical plant, to other libraries, schools or industry.

The common denominator to all of the narrow-band devices is the communications line which may consist of either a dedicated or dial-up telephone line.

Funding support must be provided beyond the initial cost of the equipment to provide for supplies, maintenance and spare parts, and staff salaries for those who will operate the equipment. Considerable resistance to the introduction of new equipment and services can result when responsibility for the new equipment is given to employees who regard this responsibility as an unreasonable addition to their workload.

Frequently, the introduction of new technology is made possible by a Federal grant which supports the project for only a limited time, usually one year. The record for continuation of these projects beyond the Federally funded period has not been encouraging. The reasons for noncontinuation of these projects are various, but the most frequent reason is that little thought was given to the continued funding support for the project until the Federal support was discontinued.

If a library has identified a well-defined application for narrow-band graphics transmission equipment, the engineer can assist in the design of an appropriate system and the choice of optimum equipment. The design of an optimum system is best accomplished by an engineer possessed of an "open mind" with respect to the comparative merits of the various equipments available on the market. There is available "systems planning" and "engineering assistance" from equipment manufacturers, but the persons providing this service are often, and understandably, oriented toward the products of their employers.

The integration of technology into an existing system requires a good deal of thought and preplanning. A trial or "de-bugging" period is often desirable to minimize the traumatic effect that equipment malfunction may have on an existing system. Often the success of technology is enhanced when the staff personnel who will be utilizing the equipment participate in the planning and procurement stage and are given careful and complete training in the operation and care of the equipment.